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AN ANALYSIS OF A SUSTAINED FLIGHT OPERATION TRAINING MISSION IN NAVY ATTACK AIRCRAFT

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13. ABSTRACT *(Maximum 200 words)*

As part of a sustained flight operations (SUSOPs) research project, we had an opportunity to evaluate the performance of aircrews from three squadrons attached to Carrier Air Wing (CAW) 15. These squadrons were involved in a practice, long-range, overwater, strike mission from the USS CARL VINSON (CVN-70). At that time, the CARL VINSON was underway from Pearl Harbor, Hawaii, to Alameda, California. The purpose of this investigation was to evaluate performance changes during the simulated SUSOP. Pre- and postmission performance was compared using *t* tests, at the 95% confidence level. Results showed a significant improvement in the ability to perceive noise-degraded speech and a significant increase in carrier landing scores. No changes were found in cognitive performance on a computerized performance assessment battery (PAB).

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SUMMARY PAGE

THE PROBLEM

As part of a sustained flight operations (SUSOPS) research project, we evaluated the performance of three squadrons from Carrier Air Wing (CAW) 15. In June 1986, these squadrons were involved in a practice, long-range, over-water, strike mission from the USS CARL VINSON (CVN-70). At that time, the CARL VINSON was underway from Pearl Harbor, Hawaii, to Alameda, California (1). The purpose of this investigation was to evaluate performance decrements occurring between pre- and postmission.

FINDINGS

Pre- and postmission performance was compared using paired t tests at the 95% confidence level. Results indicated that:

1. the ability to perceive noise-degraded speech significantly improved at the 0 dB signal-to-noise ratio (S/N) condition.
2. carrier landing scores significantly increased compared to the previous 2 months average.
3. cognitive performance remained stable.
4. vision performance remained stable.

RECOMMENDATIONS

Although significant effects were found in carrier landing scores and in the ability to perceive noise degraded speech, these results were unexpected. Conclusions based on these findings are limited, and further research is recommended to address certain issues:

1. cyclic operations where a re-strike capability is desired.
2. continuous operations where there is no scheduled aircrew rest.
3. single mission operations where the length of the mission is longer than that investigated here (approximately 11 h 45 min from brief to recovery).
4. other types of missions and aircraft.
5. the possibility of using short-acting hypnotics to aid in pre-mission rest and stimulants to aid in maintaining flight performance.

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INTRODUCTION

Advances in military technology and resultant changes in doctrine dictate that future conflicts will likely be high-intensity sustained operations (SUSOPS) lasting several days to weeks. Because additional forces may not be immediately available, aircrews may be required to perform at intense workload levels for extended periods with minimal or no sleep. Rest will be dictated by the nature of the situation and may be fragmentary. Even when able to sleep, aircrews will be expected to awaken quickly to fly their missions. It is imperative that high levels of performance be maintained under these severe conditions (2).

The operational consequences of sleep deprivation have long been recognized. The most likely sleep problems encountered by aircrews are fragmented sleep associated with partial sleep loss, disruption of sleep-wakefulness cycles, and circadian desynchronization (3). As sleep deprivation continues, the individual's performance may continue on a reasonably acceptable level, broken by lapses of attention. Sleep-deprived subjects may carry out tasks accurately, but their periods of accuracy become briefer and more infrequent as the deprivation continues. The sequel to sleep deprivation is brief intermittent lapses in performance that increase in frequency and duration. Impaired performance is seen as missed signals and errors of omission. Several factors combine during high-workload schedules to impair ability including cumulative sleep loss, the fall in performance during the early morning hours related to circadian rhythmicity, irregularity of rest, and the length of the duty period (4). Studies of total sleep deprivation have shown that substantial reductions (greater than 30%) occur in mood and performance after 18 h of continuous testing, and generally unacceptable performance (greater than 60% reductions) occur following 42 h of sustained wakefulness (2).

Given these documented performance effects, we anticipate that Navy aircrews experience appreciable performance decrements as a result of extended flight operations. The purpose of this study was to compare the performance of Navy aircrew members on a battery of cognitive, acoustical, and visual tasks administered before and after a practice, over-water, long-range, air strike.

METHODS

SUBJECTS

The participants were 20 male Navy pilots or bombardier-navigators (BNs), age 31 $\pm$ 4.8 years, assigned to three Navy attack squadrons from Carrier Air Wing (CAW) 15. Carrier Air Wing 15 was aboard the USS CARL VINSON participating in a practice, long-range, over-water, air strike. Nine of the 25 original subjects were scheduled to take the cognitive test battery, however, one was removed from the study due to a medical problem and another for technical reasons. Eight subjects were assigned to vision testing, however, two were removed for technical reasons. Eight subjects were designated to participate in acoustic testing, however, one was removed from the study for technical reasons.

COGNITIVE TESTS

Essex Corporation 3201A microprocessors (5) were selected to collect the cognitive performance data as the units are small and easily transportable. The microprocessors were programmed with a performance assessment battery (PAB) consisting of abbreviated forms of pattern recognition, grammatical reasoning, Sternberg memory task, code substitution, and four-choice reaction time tests, in that order. Visual displays were presented on a liquid crystal screen, which was adjusted to maximum contrast by the participants before the start of each testing session. Each computer was placed on a separate desk in the same state-room.

The state-room was air conditioned. Noise levels ranged from approximately 90 to 105 db (SPL), depending on the type of aircraft and flight operations being conducted at the time (6). Numerous distractions and confusion due to subjects entering and leaving during training/testing sessions was unavoidable as space on the ship was limited, and only one state-room was available. Illumination in the state-room was consistent with normal office lighting.

Nine subjects received four training sessions before data collection. Not all subjects could comply with the schedule described in the experimental procedure due to illness and operational commitments. One had to discontinue for medical reasons. One completed training but did not launch because of aircraft problems. Pre-mission and postmission testing were conducted in the same state-room.

Testing required about 5 min per session. In these tasks, the number correct, the number of errors, and the mean correct reaction time were recorded. A brief description of each test follows.

Pattern Recognition

This task tests visual pattern recognition and spatial memory (7). Participants were simultaneously presented two patterns of asterisks side-by-side on the screen. The patterns were either identical or different. The subjects were asked to type the "S" (same) or "D" (different) key with their left hand to indicate whether they thought the patterns were the same or different from each other.

Grammatical Reasoning

This is a direct adaptation of a task developed by Baddeley (8). It is a linguistic task requiring knowledge of English grammar and syntax. It assesses the ability to determine whether various simple sentences correctly describe the relational order of two letters.

During each trial, the letter pair "AB" or "BA" was displayed along with a statement that either correctly or incorrectly described the order of the letters within the pair (e.g. "B FOLLOWS A --- AB", or "A IS NOT PRECEDED BY B --- BA"). The subjects decided as quickly as possible whether the statement was true or false and pressed either the "T" (true) or "F" (false) key with their right hand to indicate matches and mismatches, respectively.

Sternberg

This is a modification of a memory search task first described by Sternberg (9). The test examines the ability to search items held in memory for the presence of a "probe" item.

A modification of what has been termed the Visual-Varied Set version (10) was used. A set of four numbers was displayed for 1 s (the "memory set"). Two seconds later, a single digit was displayed (a "probe digit"). Participants were asked to press "T" (probe digit was in the memory set) or "F" (probe digit was not in the memory set) with their right hand. A series of five probe digits were individually presented following each memory set, after which a new memory set and five associated probe digits were individually presented in repeating cycles.

Code Substitution

The Code Substitution Test was a modification of the one described in the Wechsler Adult Intelligence Scale (WAIS) (11). It is designed to test associative learning ability and perceptual speed.

A group of nine letters was displayed with associated numbers at the top of the screen:

F X S M V L U R C

(3) (4) (9) (8) (5) (6) (2) (1) (7)

Below this master list, two rows of letters and blank parentheses were displayed:

R F R M C S X L V

() () () () () () () () ()

X M V F S C L C U

() () () () () () () () ()

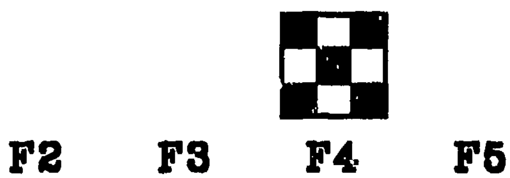
Participants were asked to fill in the blank parentheses with the matching numbers from the code at the top of the screen, as shown in the example below:

R F R M C S X L V

(1) (3) (1) (8) (7) (9) (4) (6) (5)

Four-choice Reaction Time Test

The Four-choice Reaction Time Test was based on one developed by Wilkinson and Houghton (12). Four checkered blocks were displayed at the bottom of the screen located over each of the function keys that were labeled F2 through F5. After 1 s, the four blocks disappeared and were replaced by a checkered block over one of the four function keys as shown.



When the participant responded by pressing the function key under the checkered block a checkered block appeared over another key or, at times, over the same key. The subject would respond by pressing the function key under the checkered block again and the task would continue.

VISION TESTS

Four vision tests were administered using a portable Visual Function Tester (Model VFT-1) developed by the U.S. Air Force Aerospace Medical Research Laboratory (13). The tests included critical flicker fusion frequency, cyclophoria, heterophoria, and stereopsis. A brief description of each test follows.

Critical Flicker Fusion Frequency

Critical Fusion Frequency (CFF) is the frequency at which a flickering light appears to be steady (14). The CFF provides a measure of temporal resolution, which depends on several functional characteristics of the visual system (15) and is also a reflection of physiological state (13). If CFF changes, nervous transmission speed may be affected due to fatigue or other physiological changes occurring at the synapses (13). "Normal" retinal CFF rates vary between 50 and 70 Hz (15).

A blinking light was viewed by both eyes, and the frequency of blinking was increased until the light appeared to be steady. The CFF test stimulus was a circular patch, approximately 5 deg in diameter, retro-illuminated by a "yellow" flat LED. To test for fovea CFF, the participants were instructed to look at the test light. To test for peripheral CFF, participants were instructed to look at a fixation dot located several degrees to the right of the CFF patch (13).

Cyclophoria

Tilting the head to the right or left will result in the eyes torquing slightly in the opposite direction in an attempt to compensate and keep the retinal image properly oriented. Head tilt, as detected by the vestibular system, is partially compensated in the visual system by the action of the oblique muscles of the eyes (13).

The stimuli used to measure this are shown in Fig 1. The circles help fuse the targets for vertical and horizontal displacements, while allowing free torsional movements. There is no fusion stimulus for torsion. When viewed binocularly, the arrow appeared to point to one of the numbers. Participants were asked to identify the number to which the arrow pointed. With no rotation, the participant will report that the arrow is pointed to 4.5. Each number represents one deg of rotation. Ninety deg of rotation are represented, 45 deg on each side of true vertical.

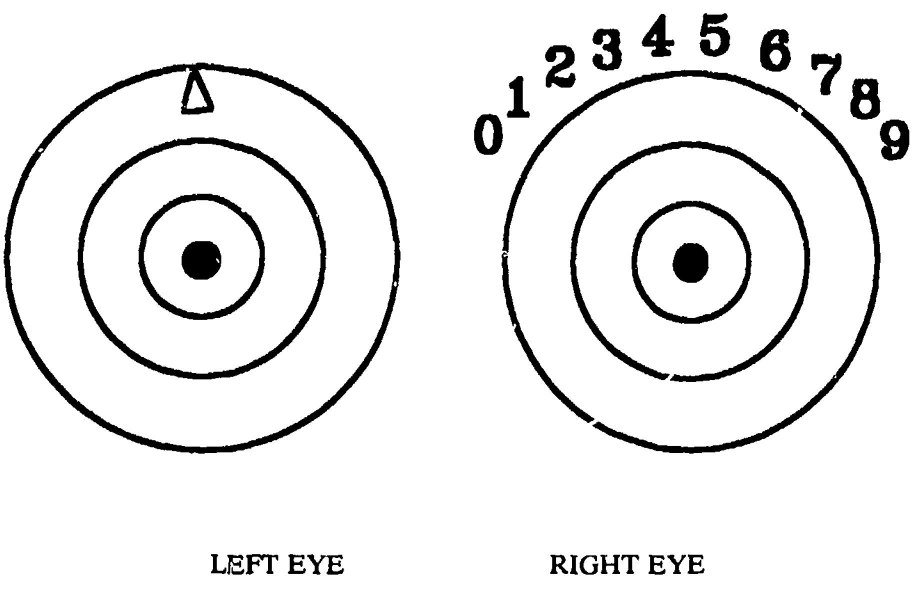


Figure 1. *Cyclophoria targets.*

Heterophoria

The lines of sight of both eyes normally intersect at the object of regard (target), and the image falls on both fovea. This condition is known as orthophoria. When fatigued, the lines of sight may move toward a resting position where retinal correspondence of the images is dissociated. They no longer intersect at the target, and the images do not fall on corresponding retinal positions. This condition is known as heterophoria and can be experienced as the "double vision" often reported by individuals who are tired or fatigued (13).

The direction in which the visual axes turn determines the type of heterophoria. In esophoria, the visual axes turn in when the eyes are dissociated. In exophoria, the visual axes turn out from each other when the eyes are dissociated. If the right axis turns up higher than the left, the condition is known as right hyperphoria. Likewise, if the left axis turns up higher than the right, the condition is spoken of as left hyperphoria (16).

The right eye target consisted of a matrix where each square represented 10 milliradians or 1 prism diopter. The left eye target was a short-duration flash that appeared as a small dot. An example of the targets as viewed by a subject is shown in Fig. 2. The subject identified the square in the matrix in which the dot appeared. An orthophoric subject should see the flash in square H-4.

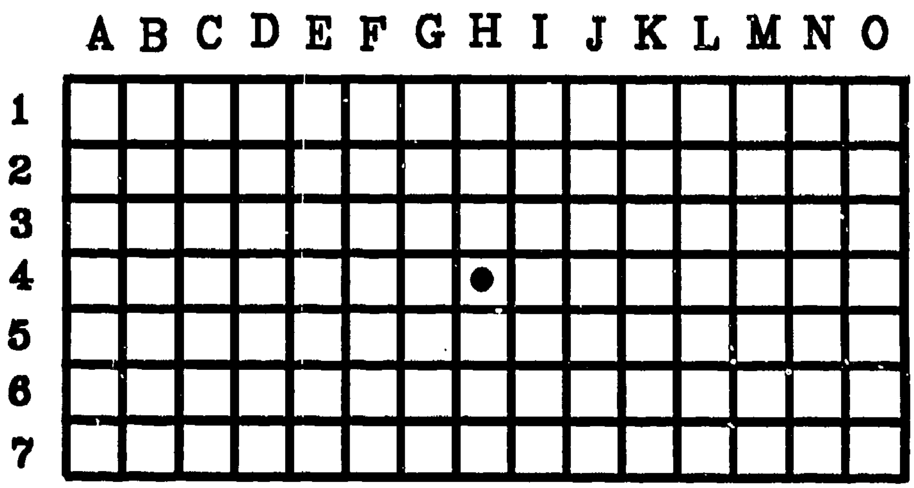


Figure 2. *Combined left and right eye heterophoria targets.*

Stereopsis

Cues for depth perception can be divided into three broad categories: monocular, movement, and binocular cues. Because the eyes are located at different positions in the head, they have slightly different views of visual stimuli and slightly different images are formed on each retina. This phenomenon, known as binocular disparity, or binocular parallax, underlies stereopsis which provides substantial cues for depth perception (14), and stereopsis has been shown to be affected by environmental conditions or physiological changes (13).

Sensitivity to retinal disparity was measured with nine test patches containing 4 dots each, as illustrated in Fig. 3. In each test patch, the subjects identified which dot appeared closer than the others. The nine test patches tested 80, 70, 60, 50, 40, 30, 22, 16, and 10 s of arc of retinal disparity, respectively.

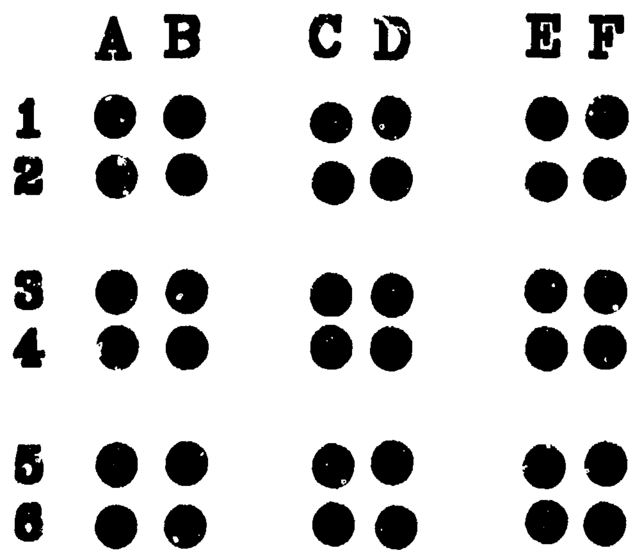


Figure 3. *Stereopsis target.*

ACOUSTICAL TESTING

Tri-Word Modified Rhyme Test

The Tri-Word Modified Rhyme Test (TMRT) is an adaptation of the widely used Modified Rhyme Test (17). The test involves peripheral and central signal processing. Changes in hearing sensitivity, speech reception, and auditory selective attention are assessed. The TMRT was designed to simulate radio communications under degraded conditions, a situation that frequently exists in flight. The TMRT is a closed-response discrimination test presented at 0 dB and + 4 dB signal-to-noise (S/N) ratios.

Multiple prerecorded target signals, degraded by a noise masker, were presented over headphones. The target signals consisted of a carrier phrase containing 3 target words. The subject was presented with printed test trials, consisting of 18 words divided into 3 groups of 6. The object of the test was to circle the word in

the first group of six that matched the first word in the carrier phrase, circle the word in the second group of six that matched the second word in the carrier phrase, and so on. For example,

"Two, do you read feel, duck, lake? Over."

kneel	feel	peel
reel	heel	eel
dun	dug	dub
duck	dud	dung
lame	lane	lace
late	lake	lay

Tape recordings of four equivalent TMRT lists of 17 trials consisting of 3 target words each (a total of 3 X 17 = 51 target words per list) were presented over a headset. A Marantz Superscope two-channel cassette deck (Model C-206LP) and Telephonics headphones (Model TDH-39) were used.

Eight subjects were tested before the mission. One subject did not launch because of aircraft problems and had to be removed from the study. Pre-mission testing was conducted in a state-room, and postmission testing was conducted in a ready-room.

CARRIER LANDING PERFORMANCE

Carrier landing scores are graded by the Landing Signal Officer (LSO) using a scale from 0 to 5:

5.0 perfect pass
4.0 above average
3.0 average
2.0 below average
1.0 wave-off due to
poor technique
0.0 unsafe

Mean carrier landing scores on this mission were compared to the previous two months' average.

EXPERIMENTAL DESIGN

The 25 subjects were divided into 3 groups: 9 in the cognitive testing group, 8 in the vision testing group, and 8 in the acoustic testing group. The training and testing protocols for each of the groups are described below.

Cognitive Testing

Results from an earlier study indicated that 4 testing sessions were required to eliminate training effects on the PAB (18). In this investigation, 8 subjects were trained twice per day on 25 and 26 June to minimize the effects of training. The order of tasking within each session was Pattern Recognition, Logical Reasoning, Four Choice Reaction Time, Sternberg, and Code Substitution. Subjects were tested twice before the launch on 27 June and twice within 1 h of recovery on 28 June.

Vision Testing

Eight subjects were tested within 48 h of the launch on 27 June and within 1 h of recovery on 28 June. No training was conducted on any of the vision tasks. Cyclophoria was measured once, critical flicker fusion frequency and phoria six times, and stereopsis nine times before and after the mission. The order of testing depended on which researcher/test became available next, and was not the same for all subjects.

Acoustical Testing

Eight subjects were tested within 48 h of launch on 27 June and within 1 h of recovery on 28 June. Instructions and practice trials were given to each subject before each of the two testing sessions.

RESULTS

COGNITIVE TESTING

The mean reaction time (± *SE*) in milliseconds for each cognitive task, and the results of the *t* test (19) are tabulated in Table 1. No significant differences were found ($p \leq .05$) between any of the pre- and postmission cognitive test scores.

TABLE 1. Mean Reaction Time (RT) for Cognitive Tasks.

Test	Premission	Postmission	*t*
Pattern recognition	769.3 ± 15.2	753.2 ± 12.5	.996
Grammatical reasoning	2510.6 ± 153.5	2515.8 ± 119.0	-.082
Four choice reaction	416.2 ± 14.0	424.4 ± 16.1	-1.060
Sternberg	666.0 ± 32.7	683.9 ± 56.8	-.529
Code substitution	1702.6 ± 69.7	1717.6 ± 79.2	-.289

VISION TESTING

Eight subjects were tested before the mission. Two subjects did not launch because of aircraft problems and had to be removed from the study. Premission testing was conducted in a state-room and postmission testing was conducted in a ready-room.

The mean score (± SE) for each vision task, and the results of the t test are listed in Table 2.

TABLE 2. Mean Scores for Vision Tasks. Asterisk Indicates Significant Differences Between Pre- and Postmission Performance.

Vision Test	Premission			Postmission			t
Cyclophoria	4.14	±	0.08	3.92	±	0.31	1.00
Peripheral CFF (Hz)	41.90	±	2.35	54.90	±	5.63	-2.63*
Fovea CFF (Hz)	52.90	±	2.27	54.20	±	1.99	-0.70
Lateral phoria (D)	-2.67	±	0.58	424.40	±	16.10	-0.64
Vertical phoria (D)	0.36	±	0.49	0.25	±	0.16	0.25
Stereopsis (s)	10.00	±	0.00	10.00	±	0.00	-----

* $p < .05$.

ACOUSTICAL TESTING

The mean error rate (± SE) for the 0 and + 4 dB S/N ratio conditions and the associated t test results are shown in Table 3.

TABLE 3. Mean Error Rate for Acoustical Tasks. Asterisk Indicate Significant Differences Between Pre- and Postmission Rates.

S/N ratio	Premission			Postmission			t
0 dB	14.9	±	5.0	10.0	±	2.6	2.3*
+ 4 dB	7.1	±	2.9	5.0	±	1.8	1.7

*$p < .05$

DISCUSSION

Examination of the vision task results revealed that peripheral CFF frequency significantly increased between pre- and postmission. This was an unexpected result. It is hard to imagine that fatigue would result in improved temporal resolution capabilities. However, the higher CFF may be due to the inherent difficulty of testing peripheral vision. In any test of peripheral vision, the subject must exercise precise control of eye position. He must not look directly at the test stimulus. Postmission subjects may have experienced greater difficulty in holding the stimulus in the peripheral retina. The data would seem to support this hypothesis. Furthermore, the postmission peripheral and fovea CFF values are identical. The postmission peripheral standard deviations are more than twice the pre-mission peripheral values. This suggests that the subjects had greater difficulty with the task postmission. This is to be expected if, in fact, the subjects did have trouble maintaining the proper eye position during the postmission peripheral CFF test. If they had inadvertently directed the fovea to view the target, then spuriously high CFF with increased variability would

be expected, as was found. This result suggests that one of the consequences of fatigue might be a difficulty in directing attention to peripheral visual information without the disruption of a fovea visual task. This possibility should be further explored because of its implications in dual tasks and visual tracking.

The auditory test results indicated a significant decrease in the mean error rate at the 0 dB level in the postmission session when compared to the pre-mission session. It is not unusual in auditory research to find a general positive transfer of training between the pre- and posttests. This is especially true if the intervening task also involves auditory signal processing. Real improvements in posttest performance can result from the auditory signal processing practice that occurs between pre- and posttesting. This improvement is a distinct possibility in the present experiment, because of the nature of the 8 h mission occurring between the pre- and postflight testing.

Unexpectedly, reaction time measures from the cognitive PAB were not significantly different between pre- and postmission. This may be a result of having a single SUSOPS mission when the aircrews were well-rested before the flight. In other words, levels of fatigue experienced in this study were less than those of other studies and apparently insufficient to be detected by the PAB.

Assuming the PAB failed to measure cognitive performance differences, we offer 4 possible explanations; our tests were insensitive, the number of subjects was not sufficiently large, the mission did not produce a significant amount of fatigue to result in measurable decrements in performance, or our subjects were not motivated. We do not suspect the sensitivity of the PAB as various forms of it have been used successfully elsewhere to measure cognitive performance (10,18).

Although 20 subjects participated in the over-all study, only 7 participated in cognitive testing, 6 the completed the vision tasks, and 7 took part in acoustic testing. Groups of this size may have been too small to yield the statistical power necessary to detect changes in performance between pre- and postflight.

Sustained flight operations are usually characterized by cyclic, extended missions separated by brief periods of rest. This was a limited (11 h 45 min), single-mission exercise with well rested aircrews prior to the mission. It is possible that the mission did not produce enough fatigue to change performance between pre- and postmission.

We also do not feel subject motivation was an underlying cause. Examination of the mean percentage correct scores for the cognitive tasks (Table 4) reveals scores comparable to those of well-motivated subjects in other studies (7-9,11,12).

TABLE 4. Mean Percentage Correct Scores for Cognitive Tasks.

Test	Premission	Postmission
Pattern recognition	90.3	91.5
Logical reasoning	81.8	86.0
Four choice reaction	97.8	97.0
Sternberg	96.7	95.5
Code substitution	94.2	95.4

CONCLUSIONS

This effort has revealed areas that could be improved in future research studies. First, placing CFF testing closer to the recovery time might minimize the effects of postmission on attention, motivation, and level of arousal. Second, training on the acoustical task prior to data collection could eliminate the possibility of improving performance on the task between pre- and postmission, as occurred here. Finally, a cyclic mission scenario would probably be more fatiguing on aircrews and produce performance changes that might be detected by the PAB.

Further research is needed in the area of extended naval flight operations. These efforts should be directed toward answering questions involving cyclic flight operations, which are typical of high-intensity aircraft-carrier operations. Extended cyclic flights will almost certainly have a much more dramatic impact on aircrew fatigue than a single isolated mission that is rehearsed and prepared for, as was the case in this study.

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